

Exploring the early universe with gravitational waves

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Most of our current knowledge about the early universe comes from the so called Cosmic Microwave Background. This background consists of photons just like rays of light, however these photons were produced when our Universe was just four hundred thousand years old. At that time the last charged particles found their opposite charge partners and the universe became electrically neutral and so, transparent to light. Since then these photons have been travelling to us to finally show us a snapshot of the sky from fourteen billion years ago. Cosmic Microwave Background is precisely that snapshot and through careful analysis it allowed us learn many details about this early time.

In these project we propose to refine studies of a different background which also could have been produced in the early universe at a time much earlier than the Cosmic Microwave Background, that is the background of gravitational waves. Gravitational waves were postulated already a hundred years ago as part of Einstein's general theory of relativity. They are tiny ripples in space time that can be produced when huge masses accelerate violently. Gravitational waves interact only gravitationally and it takes incredibly precise measurements to observe them, in fact they were observed for the first time just several years ago by the LIGO collaboration. The particular waves observed up to now were produced by a collision of two black holes.

While gravitational waves from such collisions of astrophysical objects also carry a plethora of information, our project focuses on backgrounds produced much earlier. Due to their very weak interaction gravitational waves travel almost undisturbed from the time of their production. This means the Universe was transparent to them even at its very early stages and we can observe gravitational waves created even before the time at which the cosmic microwave background was formed. This gives us unprecedented direct access to information about our Universe at times right after its birth.

In particular we wish to study gravitational waves produced thanks to phase transitions. If such a transition is strong the process resembles simply boiling water in a pot, when bubbles of the new phase in our example vapour are produced and grow changing the old phase that is water into the new one. The difference is that in cosmological phase transitions we aim to study the whole Universe is our pot and boils as the bubbles of the new phase are produced and eventually convert its whole volume to the new phase. These phases in the early universe correspond to different vacuum states of the underlying particle physics model. The difference between different vacua is simply that some particles that were massless in the old phase become massive in the new one. Today, of all known particles only the photon is massless, however, at the birth of the Universe all of known particles were massless and so at least one such transition had to take place. While this transition did not necessarily have to be strong as in our example, if it was it would produce a characteristic background of gravitational waves that would give us priceless information on the early universe.

The issue with this scenario that the proposed project will help remedy is that the modelling of the transition itself and the resulting signal is very difficult. The first standing problem is how much gravitational waves are produced during the collisions of the bubbles and how much is produced later on by the plasma that fills the Universe is stirred by the transition. Another one is modelling the signal produced by the stirred plasma. While these are already fine details, their understanding is necessary if we are to identify the particle physics model that predicts the transition in question and describes our Universe.